Information Sciences 290 (2015) 120–133

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Enabling wireless cooperation in delay tolerant networks

Vitor G. Rolla *, Marilia Curado

CISUC, Departamento de Engenharia Informática, Universidade de Coimbra, Pólo II, Pinhal de Marrocos, 3030-290 Coimbra, Portugal

ARTICLE INFO

Article history:
Received 15 April 2013
Received in revised form 1 August 2014
Accepted 13 August 2014
Available online 23 August 2014

Keywords:
Incentive mechanism
Delay tolerant network
Buffer management

ABSTRACT

This paper presents a credit-based incentive mechanism for delay tolerant networks which enables device-to-device data exchange without the support of traditional Internet service providers. The solution uses a utility function that represents the monetary value of a given data message during its journey in the network, and a buffer management optimization algorithm to prevent selfish behaviour among nodes. Virtual banking relies on an off-line central trusted authority. The paper introduces the concept of isotropic deliveries in delay tolerant networks which uses binary spray and wait forwarding strategy. Simulations with the IEEE 802.15.4 standard show the proposed incentive mechanism preventing selfish behaviour and guaranteeing more extra credits to the end-user.

1. Introduction

Incentive mechanisms for Delay Tolerant Networks (DTN) are a novel theme among wireless research circles because they potentially solve the problem of selfish behaviour among nodes. Incentive mechanisms encourage the end-user to share his opportunistic connectivity, storage capabilities and energy resources. Wireless cooperation is a trend topic in the computer networks field [6]. Currently, credit- and reputation-based incentive mechanisms are known. Credit-based mechanisms use the notion of virtual currency to guide the data exchange in DTN. Cooperation rewards virtual payment whenever the node acts as a forwarder, and such monetary value (credit) can later be used to encourage others to cooperate with it. Reputation-based mechanisms evaluate the cooperation levels of nodes and provide better services to nodes with a higher reputation. Selfish behaviour is not condoned resulting in partial or total network disconnection. Incentive mechanisms are important to encourage users to cooperate for effective information sharing [42].

Lack of instantaneous end-to-end paths occurs in delay tolerant networks. Therefore, routing solutions for these types of networks must use a store-carry-forward approach to opportunistically deliver the message to the destination. Currently, multi- and single-copy DTN routing solutions are known. The multi-copy class allows multiple copies (replicas) of the same message in the network, while the single-copy class does not allow message replication. Multi-copy DTN routing solutions, for instance spray and wait [34] and Delay Tolerant Reinforcement-Based (DTRB) [32], receive more attention from the research community because of their high delivery rates and low end-to-end delays. However, these routing solutions are known to suffer from waste of network resources. Applications based on single-copy routing solutions [36] have other type of limitations, such as long delays and low delivery rates.

Some examples of DTN applications which use multi-copy routing solutions are: urban transport system control [7], 3G offloading [4], driver to driver content sharing [9], epidemic data message exchange [31], pocket switched networks [41], multi-hop Internet access [49], conference systems [12], advertising, weather, and tourist information [20].

* Corresponding author.
E-mail addresses: vitorgr@dei.uc.pt (V.G. Rolla), marilia@dei.uc.pt (M. Curado).

http://dx.doi.org/10.1016/j.ins.2014.08.035
0020-0255/

Previous DTN studies have been often focused on the forwarding strategy adopted, assuming unlimited buffer or basic buffer management schemes. However, recent research has shown that buffer management affects the performance of DTN [17]. In addition, most of these studies assume that nodes are willing to cooperate. This is indeed true when the nodes belong to the same domain (e.g. a military network). Typically nodes do not belong to the same domain, which may lead to conflicting interests among users, especially when they have limited resources, such as battery and storage capacity.

Taking into account the possibility of user cooperation and the level of user selfishness in a DTN, the motivation of this study was to develop an incentive mechanism to encourage users to cooperate by storing replicas of the messages sent by other participants in the DTN. This paper presents a credit-based incentive mechanism for delay tolerant networks called MooF (Messages on oFfer). Such mechanism utilizes buffer management to reward the users that replicate less messages. MooF can be used when an Internet service provider is not available, or eventually to compete against the messaging service offered by the major carriers. MooF enables device-to-device data exchange without the support of traditional Internet service providers. Simulation results show MooF avoiding selfish behaviour, guaranteeing high delivery rates and promising end-to-end delay considering a DTN environment.

The next section describes the related work. Section 3 explains the concept of isotropic deliveries, and Section 4 introduces MooF. Section 5 describes the simulation and shows the results. The last section concludes the paper.

2. Related work

This section is presented in four parts: related work on DTN, related work on DTN buffer management, incentive mechanisms compatible with DTN, and a discussion subsection.

2.1. Related work on DTN

Delay tolerant networks have evolved from a system designed for space communication to a network geared towards use in extreme situations where traditional coverage does not or cannot exist. Examples of utilization scenarios for DTN include military environments, after natural disasters or terrorist attacks, developing regions, or as an alternative for network congestion. Delay tolerant networks, as the name suggests, do come with their challenges and can result in bandwidth limitations, continuous network partitions, unexpected delays, restricted energy sources, and limited transmission ranges due to obstructions (e.g. walls, buildings, and mountains). Therefore, DTN aim to solve technical problems which exist in the absence of instantaneous end-to-end paths between any source and destination nodes.

DTN routing solutions can be classified as single-copy and multi-copy [1]. Single-copy DTN conserve resources because only one copy of a message exists in the network, but experience lower message delivery rates and longer delays. A common single-copy issue concerns predicting the next opportunity of connectivity (next meeting between two nodes). An interesting study about the limitations of single-copy DTN routing solutions can be found in [36].

In multi-copy DTN, replicas of the same message exist in the network. A complete epidemic solution replicates a message whenever two nodes meet with the idea that one of these copies shall reach the destination [38]. Multi-copy routing solutions can be sub-classified in flooding-based and quota-based solutions [27]. In flooding-based solutions, if storage resources and mobility allow, it is possible for every node in the network to have a replica of the same message. Examples of flooding-based solutions are Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) [23] and DTRB [32]. The quota-based solutions intentionally limit the number of replicas. Examples of quota-based solutions are the spray and sait family [34] and Adaptative Reinforcement Based Routing (ARBR) [8]. Because of successful delivery rates, multi-copy DTN routing solutions are favoured by the research community. Waste of network resources, scalability, and congestion are common issues found in some of these routing solutions. Epidemic information spreading amongst IEEE 802.11p [13] vehicular nodes (e.g. advertisements and traffic conditions) is an example of application of multi-copy routing.

The forwarding strategy utilized in this paper is Binary Spray and Wait (BSW) [34]. BSW is part of the spray and wait family. The protocol restricts the number of message copies in the DTN, improving network resource efficiency. Each message created in the system has a maximum replication number c attached to it. The number c represents the upper bound number of replicas of the same message in the network. Any node with $c > 1$ message copies, forwards $c/2$ and keeps $c/2$ copies when in contact with another node without a copy (*spray* phase). When a node has only one copy of the message, it switches to direct transmission, i.e., the node will store the message with hope to meet its destination (*wait* phase). BSW is a multi-copy quota-based DTN routing solution, thus replications of the same DTN data message occur in the network. Section 3 explains the BSW routing solution in detail, introducing the concept of isotropic deliveries. Section 4.2 presents the BSW implementation in the network simulator. The remaining related work discusses buffer management, and incentive mechanisms in the context of DTN.

2.2. Related work on DTN buffer management

Recent research shows that buffer management affects the performance of DTN routing significantly [47,17]. Buffer limitations in multi-copy DTN routing solutions can be overcome with the use of intelligent buffer management schemes [35]. Indeed, buffer management is one of the constraints that make the DTN routing problem NP-hard [1].